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International Practice of Compensation for Damage Caused by Environmental Violations in the Management of Tailings Storage Facilities and Waste Dumps

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Abstract

The purpose of the study is to examine and standardise international practices for compensating for environmental damage caused by violations in the management of tailings storage facilities and waste dumps. The study identifies effective compensation mechanisms used in Brazil, Canada, Hungary, the United States, Australia, and European Union countries and analyses various approaches to damage assessment and compensation. It reviews key frameworks such as the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), the FY 2022–2026 Strategic Plan of the Environmental Protection Agency (EPA), Directive 2008/99/EC of the European Parliament and Council on the Criminal Law Protection of the Environment, the Canadian Environmental Assessment Act, the Canadian Environmental Protection Act, and the principles of the International Council on Mining and Metals (ICMM). According to the study, Brazil, Canada, Hungary, the United States of America, Australia, and European Union countries have implemented stringent regulations for the design, management, and oversight of tailings storage facilities, which reduces the risk of accidents. The global adoption of these regulations could mitigate ecological disasters and optimise damage compensation procedures. Companies violating environmental standards are legally required to compensate for the harm they cause, including both ecological restoration and compensation for damage suffered by victims. The necessity of global cooperation and experience-sharing in preventing environmental violations and addressing their consequences is a critical factor. The studied countries have established procedures for prosecuting enterprises that violate environmental legislation, particularly in the management of tailings storage facilities. Precedents in such cases underscore the importance of creating clear procedures for determining legal liability and providing compensation to victims. The practice of environmental insurance enables mining companies to create reserves for covering potential damages, thereby reducing the financial risks faced by the state and encouraging enterprises to take greater responsibility.

Keywords

Environmental protection; Conservation measures; Preventive actions; Ecosystem restoration; Environmental impact; Industrial pollution

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Introduction

Tailings storage facilities and waste dumps pose a considerable environmental threat due to the potential for toxic substance leaks, collapses, and contamination of water resources. In the past, there have been numerous incidents resulting in severe environmental disasters (e.g., Brumadinho, Brazil, in 2019; Mount Polley, Canada, in 2014; and the accident in Ajka, Hungary, in 2010), negatively affecting ecosystems and human health. The safety standards and regulations for tailings storage facilities and waste dumps are either insufficient or inadequately enforced. This situation highlights the need for an analysis of international practices and the implementation of more effective approaches to regulation and monitoring. The global nature of environmental issues demands enhanced cooperation among countries. By exploring global practices, it is possible to adopt best practices in the field of damage compensation and standardise methods for addressing environmental issues. There is a growing need for companies to act responsibly in managing industrial waste, including tailings storage facilities and waste dumps. Research into international approaches to damage compensation contributes to strengthening corporate social responsibility and fostering sustainable practices. Legislation on compensating for environmental damage remains incomplete or contains gaps. Investigating international standards and precedents can help improve national legal frameworks. Compensation for damage caused by environmental violations has a substantial economic impact. Understanding best practices in this field can help reduce costs and optimise compensation processes. Therefore, analysis of global practices of damage compensation in the context of environmental violations related to tailings storage facilities and mining industry waste is a crucial first step towards enhancing environmental safety, ensuring compliance with legal norms, and achieving justice for affected parties.

The mining industry, as noted by Kirsanov *et al*. (2022), is a vital sector of the economy in the Kyrgyz Republic. The Republic's economic growth is largely based on the extraction of industrial minerals, gold, and other metals. However, as highlighted by Shakenov, Abdiev and Stolpovskikh (2023), the uncontrolled development of this sector can pose serious environmental threats to the country, such as soil contamination, pollution of surface and groundwater with toxic metals and metalloids, deforestation, landslides, and dust emissions. Simagambetov and Seitkozha (2024) and Sternberg, Toktomushev and Ichinkhorloo (2021) examined this type of violation. According to the findings of Simagambetov and Seitkozha (2024), environmental violations, such as improper handling of tailings storage facilities and waste dumps, can have devastating consequences for the environment. Such actions can lead to soil contamination, damage to flora and fauna, and threats to human health. Sternberg, Toktomushev and Ichinkhorloo (2021) note that intensive mineral extraction without necessary safety measures can have detrimental effects on ecosystems, biodiversity, and the quality of life of residents. This activity can result in the cessation of water flows, the formation of saline lakes, and the release of hazardous materials and heavy metals, contaminating surrounding soil and water resources. Furthermore, landslides, avalanches, and rockfalls may occur, endangering populated areas.

According to the study by Igaliyeva *et al*. (2020), the tools of international cooperation in the field of compensation for damage caused by environmental offences include

international treaties, agreements, and protocols that coordinate state measures to combat environmental crimes, such as the principles of the International Council on Mining and Metals (ICMM, 2001) and the Basel Convention No. 803-14[1] "On the Control of Transboundary Movements of Hazardous Wastes and Their Disposal" 1989. Furthermore, there are mechanisms for mutual assistance and support between countries in the event of environmental disasters or damage caused by industrial activities. As noted by Dzhumagulov, Baigazieva and Eshmuradova (2024), examples of such cooperation include the exchange of information, technologies, and expertise in addressing environmental issues, as well as joint projects for monitoring and mitigating the consequences of environmental offences. Zhusupov, Mirzaeva and Orozbaeva (2024) and Sternberg, Toktomushev and Ichinkhorloo (2021) analysed the issue of international regulation for tailings storage facilities and mine dumps. According to the findings of Zhusupov, Mirzaeva and Orozbaeva (2024), international norms and standards for handling tailings storage facilities and mine dumps include a range of documents and agreements establishing standards for the placement, operation, and rehabilitation of industrial waste. For instance, the Stockholm Convention outlines states' obligations for managing hazardous waste, including mine waste dumps. The Paris Convention on the Protection of the Marine Environment and Coastal Area contains provisions related to waste disposal, highlighting the need to adhere to safety measures when using dumps in the sea. Moreover, Sternberg, Toktomushev and Ichinkhorloo (2021) noted the existence of recommendations from an international association for the mining and metallurgical waste treatment industry, aimed at improving practices for managing tailings storage facilities and mine dumps.

Several aspects remain unexplored or require further investigation. The effectiveness of existing compensation mechanisms, such as insurance, compensation funds, and other financial instruments, requires further study. It is necessary to assess the extent to which these methods provide adequate compensation to affected communities and contribute to environmental restoration. Mechanisms ensuring transparency and accountability for companies and governments also require definition. In light of the above, the purpose of the study is to examine how compensation for environmental damage caused by handling tailings storage facilities and mining waste is conducted at the international level and to develop proposals for strengthening institutional and legal frameworks regulating this type of compensation. The objectives of the study are: to explore international and national regulations governing the handling of tailings storage facilities and mine dumps; to examine examples of international practices for compensating damage caused by environmental offences related to tailings storage facilities and mine dumps; and to conduct a comparative analysis of legal mechanisms for compensation in various countries to identify the most effective practices.

[1] Basel Convention No. 803-14 "On the Control of Transboundary Movements of Hazardous Wastes and Their Disposal". (1989). https://treaties.un.org/doc/treaties/1992/05/19920505%2012-51%20pm/ch_xxvii_03p.pdf

Materials and Methods

Data Collection

The key concepts of "tailings storage facilities" and "mine dumps" are analysed using a structural-functional method. The overall structure of the industry in Kyrgyzstan is examined. The main types and functions of tailings storage facilities and mine dumps, technologies for handling tailings and mine dumps, and the basic principles and requirements for the operation and reclamation of tailings storage facilities and mine dumps are explored. The specifics of designing tailings storage facilities and dumps, considering geological and hydrological conditions, are also considered. Countries were selected for case studies based on their geographic diversity, the severity of incidents, and the robustness of their regulatory frameworks. Brazil, Canada, Hungary, the United States, Australia, and the European Union were chosen because they represent a mix of developed and developing economies with significant mining activities and varied approaches to environmental regulation. These countries have experienced some of the most notable accidents related to tailings storage facilities and mine dumps, providing valuable insights into both the consequences of environmental violations and the effectiveness of different regulatory and compensatory mechanisms.

Data collection involved gathering information on real cases of environmental violations and their consequences. Primary legal texts, including national and international regulations, were sourced directly from governmental and organisational websites to ensure accuracy and reliability. For instance, the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) (1980)[2] and the FY 2022-2026 EPA Strategic Plan (2022)[3] were obtained from the U.S. Environmental Protection Agency's official website. Similarly, Directive No. 2008/99/EC of the European Parliament and the Council on Criminal Law Protection of the Environment (2008)[4] was accessed through the EU's official legal database. The Canadian Environmental Assessment Act (2012)[5] and the Canadian Environmental Protection Act (1999)[6] were sourced from the Government of Canada's official publications. The principles of the International Council on Mining and Metals (ICMM, 2001) were obtained from the ICMM's official website. Additionally, environmental protection legislation in Australia and the management of tailings storage facilities and mine dumps in South Africa were analysed using primary legal documents and reports from relevant governmental bodies.

Data Analysis

By comparing legal approaches and practices for compensating for environmental damage in different countries, the definition of environmental violations and the

[2] Comprehensive Environmental Response, Compensation, and Liability Act (Superfund). (1980). https://faolex.fao.org/docs/pdf/usa142962.pdf
[3] FY 2022-2026 EPA Strategic Plan. (2022). https://www.epa.gov/system/files/documents/2022-03/fy-2022-2026-epa-strategic-plan.pdf
[4] Directive No. 2008/99/EC of the European Parliament and of the Council on Criminal Law Protection of the Environment. (2008). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0099
[5] Canadian Environmental Assessment Act (2012). https://www.wipo.int/wipolex/ru/legislation/details/11959
[6] Canadian Environmental Protection Act (1999). https://laws-lois.justice.gc.ca/eng/acts/c-15.31/page-1.html#h-63244

responsibility for such violations are analysed. Data collection on real cases of environmental violations and their consequences makes it possible to examine the types of environmental damage caused by tailings and mining waste and the mechanisms for assessing environmental damage. By examining historical data, the experiences of various countries, including Brazil, Canada, Hungary, the United States, Australia, and the European Union, are reviewed regarding addressing compensation for environmental damage caused by violations in the handling of tailings and mine dumps. The largest accidents in the world related to the handling of tailings storage facilities and mine dumps are analysed, namely: the collapse of the Vale tailings dam in Brumadinho, Brazil, in 2019, the destruction of the tailings dam at the Mount Polley mining site in Canada in 2014, and the accident at the aluminium plant in the town of Ajka in Hungary in 2010.

The legal aspects of international experience in the safety of handling tailings storage facilities and mine dumps are also investigated. This includes examining regulations such as the Superfund Act, the EPA Strategic Plan, EU Directive No. 2008/99/EC, the Canadian Environmental Assessment Act, the Canadian Environmental Protection Act, and the principles of the International Council on Mining and Metals (ICMM, 2001. The analysis aims to provide a comprehensive understanding of the regulatory frameworks and best practices in different regions, contributing to the development of effective strategies for managing tailings storage facilities and mine dumps in Kyrgyzstan.

Results

One of the most important sectors of Kyrgyzstan's economy is the mining industry (Figure 1). Natural resources, including coal, gold, uranium, and rare earth elements, are abundant throughout the country. These resources greatly influence Kyrgyzstan's economic structure, particularly in the mining sector and the growth of hydropower (Zakeri *et al*., 2022).

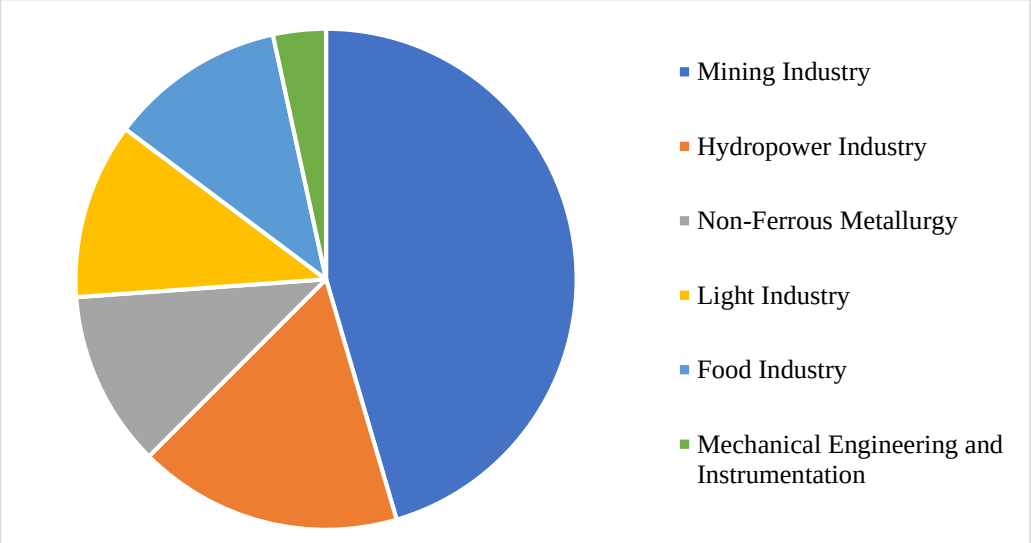

Figure 1: Structure of Kyrgyzstan's industry.

Kyrgyzstan's economy is significantly shaped by its rich natural resources, with the mining industry playing a pivotal role in its economic structure. As illustrated in Figure 1, the mining industry stands out as one of the most important sectors, contributing substantially to the country's development. The abundance of natural resources, including coal, gold, uranium, and rare earth elements, not only drives the mining sector but also influences the growth of related industries such as hydropower. This figure highlights the diverse industrial landscape of Kyrgyzstan, emphasising the prominence of the mining industry alongside other key sectors such as hydropower, non-ferrous metallurgy, light industry, food industry, and mechanical engineering and instrumentation. Understanding this structure is essential for assessing the environmental and economic impacts of tailings storage facilities and mine dumps, which are critical components of the mining industry.

The management of tailings storage facilities and mine dumps is a crucial part of the mining industry and encompasses a set of measures for handling mining production waste (Adiansyah *et al*., 2015). Tailings storage facilities and mine dumps serve as repositories for mining waste, such as processed ores, concentrates, and other industrial residues. These structures can impact the environment and require responsible management to prevent ecological disasters.

When developing dumps and tailings storage facilities, it is essential to consider local geology and hydrology to ensure structural stability and minimise the risk of collapses (Hudson-Edwards *et al*., 2024). Regular monitoring of tailings storage facilities and waste dumps is critical to detect any potential environmental hazards. Early detection of leaks and prompt mitigation actions can be achieved through monitoring air, water, and soil quality. Failures of tailings storage facilities can have severe negative environmental consequences, such as the contamination of water sources. Emergency planning and frequent emergency response drills are of utmost importance (Kukhar and Vasylevskyi, 2014). It is essential to adhere to licensing, monitoring, and reporting requirements. Furthermore, companies should consider the interests of local communities, ensuring minimal impact on their livelihoods and compliance with standards of social responsibility. Transparency and public engagement help to resolve conflicts and improve the company’s reputation. Effective management of tailings storage facilities and mine dumps requires an integrated approach that includes scientific, technical, legal, and social aspects to minimise their impact on the environment and society.

Tailing storage facilities are specialised structures for storing waste from ore processing, which contain hazardous chemical compounds and metals (Baker *et al*., 2020). Tailings storage facilities often house toxic substances, such as heavy metals, acids, and other chemicals, which can infiltrate groundwater or surface water bodies. This results in the contamination of drinking water, the death of aquatic organisms, and the disruption of ecosystems. Toxic substances from tailings storage facilities can penetrate soils, negatively affecting land fertility, agriculture, and human health (Shevko et al., 2017; 2021). Tailing storage facilities may also generate dust containing heavy metals and other harmful substances, which can be dispersed over large distances by wind, polluting both the air and the environment. Mine dumps are piles of rock left after the extraction of mineral resources that are not used in the primary production process (Gabarrón *et al*., 2019). Mine dumps occupy large areas, leading to the loss of natural ecosystems,

destruction of vegetation, and the habitats of animals. Waste heaps can be unstable, posing a risk to residents and the environment by causing landslides and soil erosion (Pawul, Kępys and Śliwka, 2022). In some cases, dumps contain sulphides that, when exposed to water and air, produce acid drainage, contaminating water bodies and soils. Wind can carry fine particles from dumps, deteriorating the quality of the air, particularly in residential areas adjacent to industrial zones.

Both storage systems, sedimentary surface ponds and stacked dry tailings, are no longer passive, especially the latter. The equilibrium states of such storage are rather complex and may involve initial "natural" conditions, those induced by technological operations in the area, or a combination of both. Dry tailings can pose a risk of causing landmass movement, and settling ponds might begin releasing their surface waters. Since both storage systems and activities in their vicinity are designed and automated through human knowledge and capabilities, the responsibility for ensuring safety regarding potential hazards also lies with humans. It is necessary to discuss whether such human activity is ongoing or has taken place. The identification and diagnosis of damage to such formations is the subject of this study. Extraction of solid minerals, such as metallic ores or industrial minerals, forms mine dumps. Surface mining operations result in the generation of significant masses of waste rock. Out of 100 tonnes of mined ore, 95 to 10% consists of waste rock (Kalisz *et al*., 2022).

Environmental violations in the management of tailings storage facilities and mine dumps include various actions and omissions that result in environmental pollution and pose risks to human health. The main violations in this area, according to Talukder *et al*. (2024), include:

- Improper management of tailings storage facilities (failure to comply with storage and management standards for tailings facilities can lead to the release of toxic substances and the contamination of soil, groundwater, and surface water);
- Violation of construction and operational standards (the use of substandard materials or technologies during the construction of tailings storage facilities and mine dumps, and neglect of operational regulations can cause structural failures and leaks of hazardous substances);
- Lack or insufficiency of environmental monitoring (the absence of continuous monitoring of the condition of tailings storage facilities and mine dumps may delay the detection of risks and emergencies);
- Violation of waste storage conditions (improper storage of waste, such as toxic metals, chemicals, and other pollutants, can lead to prolonged environmental contamination);
- Illegal waste disposal (disposal of tailings or dumps without permits and consideration of environmental standards);
- Absence of emergency response plans (non-compliance with requirements for planning and preparedness for emergencies, which can exacerbate the consequences of accidents at tailings facilities);
- Insufficient reclamation of territories (neglecting obligations to restore disturbed lands after the cessation of operations at tailings facilities and dumps, which can lead to further degradation of landscapes and ecosystems).

These violations highlight the importance of adhering to environmental standards and conducting regular monitoring in the management of tailings storage facilities and mine dumps, as well as the need to implement effective control and accountability mechanisms. Compensating for the damage caused by environmental violations in the management of tailings storage facilities and mine dumps is a critical task for many countries, as accidents and leaks from these facilities can lead to serious environmental and social consequences (Shevko, Aitkulov and Badikova, 2022). The experience of various countries in addressing these issues includes legal measures, compensation systems, international standards, and environmental restoration practices. Incidents demonstrate the necessity of strengthening controls over environmental violations and developing stricter regulatory frameworks to prevent catastrophes in the management of tailings storage facilities and mine dumps. In 2019, in Brazil, in the municipality of Brumadinho, more than 270 people lost their lives due to the collapse of a tailings dam owned by Vale, resulting in extensive environmental damage. The authorities introduced stricter safety regulations for tailings storage facilities and required companies to pay compensation to the affected families and finance ecosystem restoration (Cambridge and Shaw, 2019). Preliminary data suggested that one of the causes of the accident could have been improper waste management and insufficient maintenance of the facility. As a result, there was significant environmental pollution, contamination of water and soil, and the destruction of local flora and fauna. The disaster affected residents of nearby villages and the region's agriculture and ecological systems. This tragedy led to serious consequences and required immediate action to mitigate the damage and prevent similar incidents in the future. The fines imposed on Vale totalled over USD 7 billion, but critics argue that this amount is insufficient to address the long-term ecological and social damage. The compensation did not fully account for the loss of biodiversity, long-term health impacts on affected communities, or the economic losses incurred by local businesses. Additionally, the restoration efforts funded by Vale have been slow and faced challenges due to the complexity of the environmental damage.

The collapse of the tailings dam at the Mount Polley mining site (Canada, 2014) led to the spillage of 24 million m^3 of toxic waste into lakes and rivers. The environmental consequences included the death of fish and contamination of water bodies used by the local population. This largest tailings disaster in Canada's history, causing severe consequences for the environment and society, and the impact of the incident is still the subject of discussion and analysis (Holmes, 2024). An independent investigation revealed technical errors in the design and operation of the facility. The company was required to pay substantial fines, compensate the affected parties, and fully restore the damaged area. Imperial Metals was fined and required to pay for restoration, but the amounts were criticized for being disproportionately low compared to the environmental and social harm caused. The cleanup efforts have been ongoing, but their effectiveness remains debated, as full restoration of the affected ecosystems is unlikely. The accident at the aluminium plant in the town of Ajka (Hungary) in 2010 resulted in the spillage of one million m^3 of hazardous red sludge, contaminating waterways and damaging 40 km^2 of land. Ten fatalities were reported, along with more than ten affected communities (Magyar *et al*., 2023). Toxic compounds were released into the environment as a result of a technological failure, which caused the accident. It resulted in the widespread occurrence of diseases among the local population and contamination of the soil, water, and air surrounding the plant. The primary factors contributing to the

disaster were improper management of the production process and inadequate handling and storage of chemicals. The event had a devastating impact on the local economy, created serious health risks for the population, and caused an environmental catastrophe. The fines and compensation mandated after the disaster were significant, but the long-term environmental and health impacts on the region have not been fully addressed. Restoration efforts, while ongoing, have not yet achieved measurable success in reversing the contamination of soil and water resources.

Typical consequences of tailings disasters include the contamination of surface water and soil with toxic substances, the destruction of aquatic and forest ecosystems, threats to human and animal health, and significant economic losses for local communities and businesses (Bragina *et al*., 2018; Shumka *et al*., 2020). Furthermore, disasters can lead to a decrease in groundwater levels, creating problems for agriculture and the provision of drinking water. It is important to conduct further research to better understand and consider all possible consequences of tailings disasters and to take preventive measures. International experience in the field of tailings storage safety allows for the examination of various approaches and methods used in other countries to prevent catastrophes. For example, Australia has a strict regulatory and supervisory system for tailings storage facilities, which includes regular inspections and mandatory licensing of facilities. In the case of violations, companies are held accountable for the full restoration of the environment and are required to pay compensation to the affected parties. The establishment of reserve funds is also a common practice, aimed at covering rehabilitation costs in the event of accidents.

The United States Congress adopted the Comprehensive Environmental Response, Compensation, and Liability Act (1980)[7], which is also known in the United States as the Superfund Program. In addition to imposing taxes on the oil and chemical industries, the law grants the federal government broad jurisdiction to take immediate action in response to actual or potential releases of hazardous materials that could pose a threat to the environment or public health. Tax revenues amounting to $1.6 billion over five years were directed into a trust fund for the reclamation of hazardous waste disposal sites that had been left uncontrolled or abandoned. The federal government funds the programme to clean up contaminated areas, specifically from tailings storage facilities and mine dumps. Funding may be provided for the restoration of contaminated lands, and responsible companies may be required to reimburse the expenses. The Superfund Program is involved in cleaning up polluted sites, including tailings storage facilities and mine dumps. Companies responsible for pollution are required to fund restoration efforts and compensation. If the responsible parties are unable to cover the costs, funding is provided from a special government fund. The program operates on the "polluter pays" principle, which obliges companies to bear the full costs of remediation. According to the FY 2022-2026 EPA Strategic Plan (2022), companies that violate environmental standards may be fined and required to perform clean-up activities for contaminated areas.

However, the effectiveness of compensation tools, such as insurance schemes and funds, varies significantly. Insurance schemes often struggle to handle long-term ecological damage, such as decades-long groundwater contamination, as they are typically designed

[7] Comprehensive Environmental Response, Compensation, and Liability Act (Superfund). (1980). https://faolex.fao.org/docs/pdf/usa142962.pdf

to cover immediate clean-up costs. This mismatch can leave communities and ecosystems vulnerable to prolonged harm. For instance, while insurance may cover the initial costs of containing a spill, it may not adequately address the long-term health impacts or the extensive restoration efforts required to reverse environmental degradation. Compensation funds, such as the Superfund in the U.S., are also not without flaws. Many Superfund sites remain underfunded, leading to delays in clean-up efforts and inadequate restoration. The funds often fall short of covering the full scope of environmental damage, particularly in cases of large-scale or transboundary pollution. This underscores the need for more robust funding mechanisms and stricter enforcement of compensation obligations.

Transboundary compensation is another critical area that requires attention. When pollution crosses borders, such as a tailings spill in Canada affecting U.S. waters, international courts play a crucial role in addressing disputes. These courts must navigate complex legal frameworks and jurisdictional issues to determine liability and compensation. For example, the International Court of Justice (ICJ) and regional courts, such as those within the European Union, often rely on environmental treaties and directives to resolve transboundary disputes. However, the process can be lengthy and contentious, highlighting the need for stronger international cooperation and harmonised environmental laws. In Hungary, after the disaster at the red sludge lake in 2010, companies were required to contribute to the restoration costs (Nagy *et al*., 2019). The dam of the pond collapsed, and over a million cubic meters of red clay and water spilt into the surrounding areas. The catalyst for the catastrophe was the accumulation of aluminium production waste at the plant site. Poor management and insufficient technical infrastructure also contributed to the incident, which resulted in the deaths of dozens of people and environmental damage. Compensation for the damage caused by environmental violations in the handling of tailings storage facilities and mine dumps can take various forms, depending on the country and its legislation.

Within the European Union, Directive No. 2008/99/EC of the European Parliament and the Council on Criminal Law Protection of the Environment (2008)[8] obliges companies to compensate for environmental damage, including pollution from tailings storage facilities and waste dumps. This procedure involves both financial compensation and specific clean-up actions. Member States may employ various mechanisms for funding compensation, such as environmental funds or pollution charges. Thus, the EU's Directive 2008/99/EC focuses on criminal liability, imposing penalties such as fines or imprisonment for individuals or companies that commit environmental crimes. This approach aims to deter violations through the threat of criminal prosecution, reflecting the EU's emphasis on accountability and deterrence. In Canada, laws such as the Canadian Environmental Assessment Act (2012)[9] and the Canadian Environmental Protection Act (1999)[10] require companies to compensate for damage and finance clean-up measures. Responsible parties may be compelled to undertake restoration work on contaminated sites or pay fines. There are also initiatives aimed at the rehabilitation of

[8] Directive No. 2008/99/EC of the European Parliament and of the Council on Criminal Law Protection of the Environment. (2008). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0099
[9] Canadian Environmental Assessment Act (2012). https://www.wipo.int/wipolex/ru/legislation/details/11959
[10] Canadian Environmental Protection Act (1999). https://laws-lois.justice.gc.ca/eng/acts/c-15.31/page-1.html#h-63244

environmentally contaminated areas. South Africa, with its long history of mining, incorporates tailings storage management as a key component of its industrial regulations. To prevent damage, strict monitoring standards have been implemented, and companies are required to regularly submit reports on the condition of facilities and plans to mitigate risks (Dladla and Ramsandi, 2022). In the event of an incident, companies must not only compensate for environmental damage but also participate in long-term restoration programs and support local communities. In Australia, environmental protection legislation also includes provisions for compensation for damage. Environmental protection legislation holds companies accountable for pollution from tailings storage facilities and waste dumps, including the obligation to clean up affected areas. Restoration programs for the remediation of contaminated sites are in place, funded either by the state budget or the responsible companies.

The role of non-state actors, such as NGOs and local communities, is crucial in compensation processes for environmental violations, yet it is often overlooked. In Brazil, communities affected by disasters like the Brumadinho dam collapse actively participate in damage assessments and fund allocation through public consultations and partnerships with NGOs, ensuring their needs are addressed. Similarly, in Canada and Australia, Indigenous rights are increasingly integrated into compensation mechanisms, with Indigenous communities playing key roles in environmental assessments, restoration efforts, and compensation negotiations. For instance, after the Mount Polley tailings dam collapse, Indigenous groups in British Columbia advocated for comprehensive restoration and cultural heritage protection. However, challenges remain, as these communities often lack resources and political influence, highlighting the need for capacity-building initiatives and inclusive regulatory frameworks to ensure fair and effective compensation processes.

Each country has its own specific legislative and implementation approaches to environmental accountability, but the common goal is to compensate for damage and restore the environment (De Sadeleer, 2020; Yarin *et al*., 2023). This aim is achieved through the introduction of stringent regulations and standards to prevent accidents, as well as mandatory measures for compensation. Companies are required to establish insurance funds or reserve resources to cover potential damage. The application of international standards and recommendations, such as the principles of the International Council on Mining and Metals (ICMM, 2001), is also encouraged. Obligations to conduct restorative work are introduced to minimise long-term environmental impacts.

Compensation for harm caused by environmental violations necessitates clear and effective legal mechanisms, corporate accountability, and active state involvement in monitoring and supporting restoration processes. Judicial practice plays a crucial role, shaped by court decisions that establish legal approaches and procedures for case review, thereby setting precedents in environmental responsibility, harm compensation, and the rehabilitation of damaged areas. In 2019, following the collapse of a tailings dam at Vale's mine in Brazil, multiple lawsuits were initiated. The company was accused of negligence and breaches of safety regulations, which resulted in the deaths of 270 people. Vale was required to compensate the victims and their families and to finance environmental restoration efforts. As a result of the court rulings, the company faced fines exceeding USD 7 billion (Rose, Mugi and Saleh, 2023).

After the collapse of the tailings dam at the Mount Polley mining site, the Canadian mining company Imperial Metals was held accountable for violating environmental regulations (Nunn, 2022). The government of British Columbia and those affected by the pollution initiated legal proceedings, seeking compensation for damage caused to the ecosystem and local communities. Investigations revealed that the company had breached waste management requirements, leading to a large-scale spill of toxic materials into water bodies. The company was obligated to pay multimillion-dollar fines and undertake restoration work. Legal proceedings following the accident at the MAL Zrt aluminium plant in Hungary questioned whether the company was guilty of negligence, which resulted in a spill of red mud, a toxic by-product of aluminium. The disaster claimed 10 lives, and around 150 people sustained injuries. The court found the company guilty and mandated the reclamation of polluted lands and compensation for the victims. The company's management was also held criminally liable for breaching environmental protection requirements.

Methods for assessing damage to natural resources, determining the cost of restoration activities, approaches to joint liability among multiple polluters, compensation for environmental harm, commercial use of natural resources (including market-based approaches), violations of compensation procedures, and the possibility of involving unidentified parties are foundational aspects of judicial practice. To address environmental challenges in Kyrgyzstan, suggestions such as establishing an environmental liability fund must be tailored to the country's specific context, including its limited institutional capacity and mining-dependent economy. For instance, Kyrgyzstan can implement stringent monitoring systems akin to those in Australia by leveraging international partnerships and technological assistance. Collaborations with organizations like the United Nations Environment Program (UNEP) or the World Bank could provide access to advanced monitoring technologies, training programs, and funding to enhance the country's regulatory capacities. Additionally, Kyrgyzstan could adopt a phased approach to monitoring, starting with high-risk areas and gradually expanding to cover all mining operations, ensuring that limited resources are used efficiently.

Lessons from Hungary's 2010 disaster are particularly relevant for Kyrgyzstan's mining-dependent economy. The Ajka aluminium plant accident highlighted the importance of robust emergency response plans, transparency, and community engagement. Kyrgyzstan can learn from Hungary's experience by establishing clear protocols for emergency preparedness, including regular drills and community training programs. Additionally, the government should prioritize transparency in reporting environmental risks and engaging local communities in decision-making processes. This approach not only builds trust but also ensures that compensation mechanisms are responsive to the needs of affected populations. Furthermore, Kyrgyzstan could implement stricter regulations for waste management and storage, drawing on Hungary's post-disaster reforms to prevent similar incidents. By integrating these lessons and adapting them to its unique context, Kyrgyzstan can strengthen its environmental governance and mitigate the risks associated with its mining industry. Modern legislation in various countries acknowledges the environmental rehabilitation of damaged areas (land reclamation), defining full compensation for harm caused to nature. However, monetary compensation is reduced by the costs of activities aimed at restoring or replacing the natural

environment. The second postulate, the "polluter pays" principle, establishes a phased allocation of obligations for compensating harm caused by pollution and for restoring or replacing natural resources. In cases of environmental violations by an indeterminate number of parties, the share of liability for the two "major" polluters is proportional to their relative responsibility. The process stipulates measures, penalties, and procedures for redistributing contributions among participants in cases of tortious or unlawful acts.

The existing mechanism for compensating environmental harm caused by violations does not sufficiently minimise ecological risks associated with the extraction and transportation of ore. The compensation amount remains among the lowest compared to the scale of environmental and economic losses, and dependence on compensatory property does not incentivise the development of affected areas. Territorial limitations on compensation payments exist almost everywhere, particularly in overloaded cities or settlements. The mechanism should be based on principles aimed at reducing spatial disparities in environmental quality within and outside mining and processing zones. All cases are based on research in ecology, economics, and law at various levels of scientific inquiry. One of the key methodologies employed was an identification tool used to substantiate the necessity for compensation for harm caused by pollution from ore extraction and mining waste management. Judicial practice in cases involving tailings dams and mine waste sets important precedents for strengthening environmental legislation and safety standards in the mining industry (Florez-Salas et al., 2023). It is aimed not only at compensating for harm but also at preventing future disasters by introducing stricter waste management standards and increasing corporate accountability.

The mining industry frequently encounters systemic issues such as regulatory capture and corporate lobbying, which undermine environmental protection and enforcement. Regulatory capture occurs when regulatory bodies are influenced by the industry they oversee, leading to weakened enforcement of environmental standards and inadequate penalties for violations. For instance, in Brazil and Canada, critics have highlighted the close ties between the mining industry and regulatory agencies, resulting in lax oversight of tailings dams and insufficient enforcement of safety and environmental standards. Additionally, corporate lobbying efforts often weaken environmental regulations, as seen in the United States and Australia, where the mining industry has successfully influenced regulatory frameworks to prioritise industry interests over environmental protection. This lobbying creates a regulatory environment that compromises stringent safety and environmental standards, exacerbating the risks of ecological disasters and hindering effective enforcement.

In international practice, when people suffer from environmental harm due to issues with tailings storage facilities and waste dumps, they receive compensation through a mix of legal, financial, and technological actions. These measures vary depending on the legislation of specific countries and international agreements and standards that regulate environmental responsibility. In cases of transboundary environmental violations, countries cooperate to coordinate efforts for compensation and the restoration of environmental conditions. Mechanisms of interaction, such as those between the countries of the European Union that use environmental directives to jointly address such issues, are of particular importance. International practice requires the assessment of damage to the environment to determine the scale of harm and the necessary restoration

measures. Restoration efforts may encompass land reclamation, water resource purification, and initiatives to revive biodiversity etc. Thus, the application of the "polluter pays" principle, clear legal regulation, and financial mechanisms for ensuring compensation and environmental restoration serve as the cornerstone of global practices for addressing damage caused by environmental violations in the handling of tailings storage facilities and waste dumps. Therefore, compensation for damage caused by environmental violations in handling tailings storage facilities and waste dumps is complex and multifaceted, requiring further examination.

A comparison of approaches to compensating for damages caused by the mishandling of tailings storage facilities and waste dumps across various countries reveals a diversity of strategies regulating environmental responsibility. These approaches differ depending on local legislation, the degree of development of environmental protection mechanisms, and political and economic conditions. In light of the growing mining industry and the need to strengthen environmental legislation, Kyrgyzstan can introduce the following measures: the "polluter pays" principle: Kyrgyzstan should implement strict regulations requiring companies to compensate for damage caused to ecosystems fully; establishment of an environmental liability fund: it is crucial to develop a national fund into which mining companies are required to contribute funds to address potential environmental disasters. This would enable the prompt covering of expenses for restoration measures; monitoring and control: enhancement of monitoring the condition of tailings storage facilities and waste dumps and implementation of early warning technologies for environmental disasters; international cooperation: Kyrgyzstan should actively cooperate with global organisations and partners to improve environmental standards and adopt advanced practices; environmental insurance: mandatory environmental risk insurance for mining companies will help mitigate the financial consequences of disasters and accelerate the restoration process; public reporting: the introduction of mandatory public reporting on the state of tailings storage facilities and waste dumps will increase the transparency and accountability of mining companies. These measures will not only prevent environmental disasters but also establish clear rules for responsibility and compensation, promoting the sustainable development of the mining industry in Kyrgyzstan.

Developing nations, such as Kyrgyzstan, face significant challenges in replicating these frameworks due to resource constraints, institutional weaknesses, and corruption. In Kyrgyzstan, limited financial and technical resources hinder the establishment of robust regulatory bodies and enforcement mechanisms. Additionally, corruption can undermine the independence of regulatory agencies, leading to weakened enforcement and preferential treatment for well-connected industries. Without strong institutional frameworks and public accountability, environmental regulations may exist on paper but fail to translate into effective enforcement. Furthermore, developing countries often lack the specialised expertise and infrastructure required to monitor and address environmental violations, making it difficult to implement and sustain comprehensive regulatory systems.

A preventive compensation model, such as mandatory escrow accounts for mining operations, could revolutionise how environmental risks are managed. Under this model, mining companies would be required to establish escrow accounts at the outset of their

operations, setting aside funds specifically for environmental remediation, compensation, and restoration efforts. These funds would be held by an independent third party and released only in the event of an environmental violation or disaster. This approach ensures that financial resources are readily available to address damages without delay, while also incentivising companies to adhere to environmental standards to avoid drawing from the escrow account. Furthermore, the escrow system could be tied to performance-based regulations, where companies with strong environmental records are rewarded with lower escrow requirements, while those with poor records face higher financial obligations. This model not only provides a proactive mechanism for compensation but also creates a financial disincentive for environmental negligence.

The integration of digital tools, such as artificial intelligence (AI) for tailings monitoring, could transform accountability in the mining industry. AI-powered systems can continuously monitor tailings storage facilities and waste dumps, analysing data in real-time to detect early signs of structural instability, leaks, or environmental contamination. For instance, machine learning algorithms could process satellite imagery, sensor data, and hydrological information to predict and prevent potential disasters. Additionally, blockchain technology could be employed to ensure transparency and immutability in reporting environmental data, making it harder for companies to manipulate or conceal information. Digital platforms could also facilitate public engagement by providing real-time access to environmental monitoring data, empowering local communities to hold companies accountable. By leveraging these technologies, Kyrgyzstan and other countries could significantly enhance their ability to prevent and respond to environmental violations, while fostering greater trust and collaboration between stakeholders.

The preventive compensation model and the use of digital tools for accountability offer novel frameworks for addressing systemic issues in environmental governance. These approaches challenge traditional reactive compensation mechanisms by emphasising proactive risk management and transparency. They also align with broader theoretical debates on corporate social responsibility, environmental justice, and the role of technology in sustainable development.

Discussion

The compensation for damage caused by the mishandling of tailings storage facilities and waste dumps is governed by a range of regulations aimed at protecting the environment and ensuring accountability for environmental violations. Effective management of tailings storage facilities and waste dumps, along with compliance with all regulations and safety standards, can remarkably reduce the risk of environmental violations and, consequently, the need for damage compensation.

According to Cacciuttolo and Atencio (2023), in the field of mineral extraction and processing, tailings and waste rock dumps are key components of infrastructure. According to researchers, mining remains the main driver of economic growth in Kazakhstan and plays a vital role in ensuring the sustainable development of the country, despite challenges related to ecology and economic diversification. Cacciuttolo and Atencio (2023) state that tailings storage facilities are designed to store the waste or tailings produced during the extraction and processing of minerals, while waste rock

dumps are used for disposing of uneconomical materials. Tailings storage facilities are used to place fine-grained waste (tailings) left after the enrichment of minerals (Bakiev et al., 2021). These wastes often contain chemical reagents, ore residues, and water, which require safe storage. Waste rock dumps are used for accumulating solid waste, such as barren rock, which does not contain sufficient minerals for further processing (Sydorchuk, Khlyap and Andrukhiv, 2001). These facilities play a key role in minimising environmental impacts. Proper design, construction, and operation of tailings storage facilities and waste dumps help reduce the risks of water, soil, and air pollution. Tailings storage facilities and waste rock dumps are crucial components of infrastructure in mineral extraction and processing (Shirin et al., 2011). These facilities are designed for the storage and management of waste produced during the extraction and enrichment of ores, coal, and other mineral resources (Deryaev, 2024). Therefore, the author's view is worth agreeing with, and it should be added that they ensure the safety of workers and local communities by preventing potential emergencies, such as the breach of tailings dam walls.

Major accidents in the handling of tailings storage facilities and waste dumps result in severe impacts on human health, environmental damage, and significant economic losses due to the need for remediation and resource restoration (Skliar et al., 2024; Yaroshenko, Skliar and Rosenthal, 2023). Numerous violations of environmental regulations, which threaten public health and cause environmental pollution, are evident in the management of tailings storage facilities and waste dumps. Wolkersdorfer and Mugova (2022) draw similar conclusions. A more detailed study of this issue reveals that large volumes of water from waste rock dumps and tailings storage facilities present a potential threat to natural hydrological cycles. In technical terms, waste rock dumps, like tailings storage facilities, are considered a source of filtration water with solid impurities (Deryaev, 2023a). The impact of polluted water from waste rock dumps and tailings storage facilities is that when it enters rivers, lakes, or groundwater, or accumulates on the surface of underground mines, where water stagnates and slowly percolates through the rock, a natural filtration process takes place (Gudkov et al., 2017; Kuybida et al., 2019). The storage of large quantities of various reagents and other chemicals is the cause of emergencies, which may threaten not only human lives and health but also lead to irreversible consequences for the environment and neighbouring settlements. As Lumbroso *et al*. (2019) state, a feature of tailings storage facilities is that they serve as a barrier to the rapid spread of tailing material, protecting not only water bodies, water intakes, industrial buildings, and private homes but also operational offices and production premises.

Ramón and Lull (2019) highlight the importance of incentivising preventive environmental measures to build trust in regulatory bodies and the public, while also reducing subsequent costs related to liability risks, remediation, waste management, and other related expenses. This approach is crucial for encouraging proactive environmental protection and preventing pollution. However, it is equally important to complement these incentives with robust enforcement mechanisms. Such mechanisms are essential to deter violations proactively and ensure that regulations are effectively upheld. A comprehensive legal framework should be established to oversee and compensate for damages caused by environmental violations, particularly in the management of tailings storage facilities and waste dumps. This framework should prioritise environmental

protection, safeguard the interests of citizens and the state, and hold violators accountable. By balancing incentives for preventive measures with stringent enforcement, we can achieve a more effective and reliable system for environmental governance.

There are several ways to obtain compensation for damage when environmental violations occur near landfills and tailings storage facilities (Deryaev, 2023b). These systems are designed to guarantee the restoration of affected areas and hold individuals or organisations accountable for any harm they have caused to the environment. A complex legal and administrative framework governs the compensation for damages resulting from environmental violations in tailings storage and waste management. This is explained by You and Wijesinghe (2016). The process involves identifying the responsible party or parties, assessing the extent of the damage, and determining the appropriate compensation measures. In cases where environmental violations have resulted in harm, such as contamination of water sources or destruction of natural habitats, the affected parties have the right to seek compensation through legal channels. Legal compensation mechanisms may include civil lawsuits, administrative fines, or criminal prosecution, depending on the nature and severity of the violations. Government agencies and environmental protection authorities play a crucial role in overseeing the compensation process and ensuring that responsible parties meet their obligations. Furthermore, the creation of specialised funds or insurance schemes can provide financial resources for compensating environmental damage, particularly in cases where responsible parties are unable to fulfil their obligations. Overall, damage compensation mechanisms for environmental violations in tailings and waste management are intended to ensure that those responsible for the harm bear the costs of reclamation and restoration, thus promoting environmental accountability and sustainability (Lyubchyk *et al*., 2015).

According to research by Jaime-Paredes (2021), it is critical to review the relevant environmental rules and regulations, particularly those that define the duties and rights of both the responsible and the affected parties. The burden of proof, which sets the standard of evidence required to prove environmental damage liability, is a key legal consideration. This requirement entails establishing a direct connection between the responsible party's actions and the environmental harm caused, along with assessing the severity of the damage. The author's opinion is agreeable, as the legal aspects of compensation for environmental violations are complex and multifaceted. Therefore, when addressing environmental violations in the management of tailings storage facilities and waste dumps, it is crucial to understand the legal framework that regulates the compensation for the harm caused. Moreover, the legal procedure for obtaining compensation varies by jurisdiction and may involve administrative processes, alternative dispute resolution procedures, or civil lawsuits.

Environmental violations near waste dumps and tailings storage facilities can cause significant harm to ecosystems and neighbouring communities, necessitating a clearly defined procedure for compensating damages. This procedure should cover both direct and indirect impacts on the environment, as well as the effects on public health and human lives. Compensating for environmental violations in waste storage facilities and dumps involves a complex process of assessment, cost calculation, and remediation, requiring the involvement of various stakeholders. Government agencies should enforce

regulations, oversee the compensation process, and ensure adherence to legal frameworks, holding violators accountable and implementing penalties as needed. Environmental specialists are tasked with conducting thorough assessments of the environmental damage, calculating remediation costs, and developing restoration plans, ensuring an accurate and comprehensive evaluation. Affected communities must be empowered to participate in monitoring and decision-making processes, providing vital input on the impact on public health and quality of life, and ensuring that compensation measures address their needs. Organisations responsible for violations should cooperate fully with the assessment and remediation processes, provide necessary data and resources, and implement corrective actions to prevent future violations, bearing the financial responsibility for compensation and remediation efforts. The goal is to accurately assess the total damage, restore affected areas, and compensate those harmed, while also implementing preventive measures to reduce the likelihood of future violations. This may involve creating and implementing stricter laws, establishing complex tracking and reporting mechanisms, and promoting optimal waste processing and disposal methods. Raising awareness among stakeholders about the potential consequences of environmental violations and the need to comply with environmental standards is crucial. Ultimately, the compensation process aims to restore the environment, achieve justice for affected parties, and prevent further harm.

Conclusions

Environmental violations in the management of tailings storage facilities and waste dumps are a serious issue, as they can negatively impact the environment, human health, and ecosystems. Global practice shows that to effectively manage the environmental risks associated with tailings storage facilities and waste dumps, comprehensive regulations must be developed and applied, covering the entire lifecycle of the site, from its creation to reclamation. In countries with developed mining industries, such as Brazil, Canada, Hungary, the United States, and Australia, strict standards for the design, operation, and monitoring of tailings storage facilities exist, which reduce the risk of accidents. For instance, the Brumadinho dam disaster in Brazil in 2019 highlighted the catastrophic consequences of inadequate tailings management, leading to significant loss of life and environmental devastation, followed by billion-dollar fines. The implementation of such standards at the international level could minimise environmental catastrophes and facilitate compensation for damages. The “polluter pays” principle is in place, under which companies responsible for environmental violations are required to bear financial responsibility for the damage caused. This includes not only compensating the affected parties but also restoring the ecosystem. An important aspect is the need for international cooperation and the exchange of experience on preventing environmental offences and addressing their consequences.

Companies can be held legally accountable for breaches of environmental laws, especially those about tailings management. Precedents in such cases (for example, in Brazil and the USA) highlight the importance of developing clear mechanisms for legal responsibility and compensation for affected parties. Some countries (the USA, Canada) have introduced environmental insurance, enabling mining companies to establish reserves for compensating potential harm. The practice reduces financial risks for the state and promotes greater corporate accountability. In the future, countries with

developing mining sectors should adopt international standards and practices, adapted to local conditions, to minimise negative environmental impacts and ensure prompt compensation in the event of accidents.

Control over the management of tailings storage facilities and waste dumps is aimed at minimising environmental risks. This includes regular monitoring of the condition of such facilities, adherence to technological standards, and the implementation of environmental protection measures. Enterprises engaged in the extraction and processing of minerals must comply with environmental regulations. Effective management of these facilities will reduce risks to the environment and public health. One of the main limitations in examining this issue is that environmental legislation varies significantly between countries. International norms on this subject are often insufficiently specific or enforceable, making it difficult to identify the responsible parties and determine the extent of compensation for damages. Furthermore, in some countries, governments may be inclined to minimise sanctions against local businesses due to economic considerations, which hinders compensation at the international level.

One important area for future examination is the international insurance mechanisms and compensation funds for damages caused by environmental catastrophes related to tailings storage facilities. For example, analysing how insurance schemes operate in the mining industry. Another important aspect is the investigation of the transboundary impacts of tailings storage facilities and waste dumps and the mechanisms for compensating neighbouring states for damage. This includes the analysis of cases in international courts or arbitration concerning compensation for transboundary environmental damage.

References

Adiansyah, J.S., Rosano, M., Vink, S., and Keir, G. (2015). A Framework for a Sustainable Approach to Mine Tailings Management: Disposal Strategies. *Journal of Cleaner Production,* 108: 1050-1062. DOI: https://doi.org/10.1016/j.jclepro.2015.07.139.

Baker, E., Davies, M., Fourie, A., Mudd, G., and Thygesen, K. (2020). Minetailings facilities: Overview and Industry Trends. In: B. Oberle, D. Brereton, A. and Mihaylova (Eds). *Towards Zero Harm: A Compendium of Papers Prepared for the Global Tailings Review* (pp. 14-25). Switzerland: Global Tailings Review.

Bakiev, M., Yakubov, K., Koybakov, S., Khayitov, K., and Bobojanova, N. (2021). Theoretical bases for determining the velocity and suspended matter concentration in the swirling zone beyond the transverse dam. E3S Web of Conferences, 264: 03044. DOI: https://doi.org/10.1051/e3sconf/202126403044.

Bragina, E.V., Ives, A.R., Pidgeon, A.M., Balčiauskas, L., Csányi, S., Khoyetskyy, P., Kysucká, K., Lieskovsky, J., Ozolins, J., Randveer, T., Štych, P., Volokh, A., Zhelev, C., Ziółkowska, E., Radeloff, V.C. (2018). Wildlife population changes across Eastern Europe after the collapse of socialism. Frontiers in Ecology and the Environment, 16(2): 77-81. DOI: https://doi.org/10.1002/fee.1770.

Cacciuttolo, C., and Atencio, E. (2023). In-Pit Disposal of Mine Tailings for a Sustainable Mine Closure: A Responsible Alternative to Develop Long – Term

Green Mining Solutions. *Sustainability*, 15(8): 6481. DOI: https://doi.org/10.3390/su15086481.

Cambridge, M., and Shaw, D. (2019). Preliminary Reflections on the Failure of the Brumadinho Tailings Dam in January 2019. *Dams and Reservoirs*, 29(3): 113-123. DOI: https://doi.org/10.1680/jdare.19.00004.

De Sadeleer, N. (2020). *Environmental Principles: From Political Slogans to Legal Rules*. Oxford: Oxford University Press.

Deryaev, A. (2023a). Dual completion operation technology for two gas condensate reservoirs with production lifting by one column of pumping and compressor pipes. Machinery and Energetics, 14(4): 33-41. DOI: https://doi.org/10.31548/machinery/4.2023.33.

Deryaev, A. (2024). Investigation of the Gubadag deposit clay minerals properties and development of drilling fluids based on them. Mineral Resources of Ukraine, 2024(2): 62-68. DOI: https://doi.org/10.31996/mru.2024.2.62-68.

Deryaev, A.R. (2023b). Forecast of the future prospects of drilling ultra-deep wells in difficult mining and geological conditions of Western Turkmenistan. SOCAR Proceedings, 2023: 13-21. DOI: https://doi.org/10.5510/OGP2023SI200874.

Dladla, S.D., and Ramsamy, S. (2022). Practical Steps to Global Industry Standard on Tailings Management (GISTM) Compliance for Operational Tailings Storage Facilities in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, 122(6): 283-290.

Dzhumagulov, A.M., Baigazieva, D.M., and Eshmuradova, N.D. (2024). Transboundary Water Management in Kyrgyzstan: International Law Aspects. *BIO Web of Conferences*, 107: 04003. DOI: https://doi.org/10.1051/bioconf/202410704003.

Florez-Salas, J.L.T., Ramos-Saira, E.M., Joo-García, C.E., Ramos-Alave, R., Del Carpio-Delgado, F., and Laura-De La Cruz, K.M. (2023). Safety and Occupational Health Management System in Mining to Reduce Fatal Accidents in the Mining Industry. Smart Innovation, Systems and Technologies, 366: 57-67. DOI: https://doi.org/10.1007/978-981-99-5414-8_7.

Gabarrón, M., Zornoza, R., Acosta, J.A., Faz, Á., and Martínez-Martínez, S. (2019). Mining Environments. In: P. Pereira (Ed.), *Soil Degradation, Restoration and Management in a Global Change Context* (pp. 157-205). London: Academic Press.

Gudkov, D., Shevtsova, N., Pomortseva, N., Dzyubenko, E., Yavnyuk, A., Kaglyan, A., and Nazarov, A. (2017). Aquatic plants and animals in the chernobyl exclusion zone: Effects of long-term radiation exposure on different levels of biological organization. Genetics, Evolution and Radiation: Crossing Borders, The Interdisciplinary Legacy of Nikolay W. Timofeeff-Ressovsky, 1: 287-302. DOI: https://doi.org/10.1007/978-3-319-48838-7_24.

Holmes, R. (2024) Likely Resident and Biologist's Reflections on the Mount Polley Mine Disaster. *BC Studies: The British Columbian Quarterly*, 221: 185-200. DOI: https://doi.org/10.14288/bcs.no221.199786.

Hudson-Edwards, K.A., Kemp, D., Torres-Cruz, L.A., Macklin, M.G., Brewer, P.A., Owen, J.R., Franks, D.M., Marquis, E., Thomas, C.J. (2024). Tailings Storage Facilities, Failures and Disaster Risk. *Nature Reviews Earth and Environment*, 5, 612-630. DOI: http://dx.doi.org/10.1038/s43017-024-00576-4.

ICMM (International Council on Mining and Metals) (2001). Our Principles. Available online at: https://www.icmm.com/en-gb/our-principles (accessed 10 March 2025).

Igaliyeva, L., Yegemberdiyeva, S., Utepkaliyeva, K., and Bakirbekova, A. (2020). Development of Economic Mechanism Forensuring Ecological Security in Kazakhstan. *International Journal of Energy Economics and Policy*, 10(4): 240-250.

Jaime-Paredes, A. (2021). Mining Environmental Law Sand Regulations: Mexican Experience. *International Journal of Environment and Waste Management*, 28(4): 456-472. DOI: https://doi.org/10.1504/IJEWM.2021.118857.

Kalisz, S., Kibort, K., Mioduska, J., Lieder, M., and Małachowska, A. (2022). Waste Management in the Mining Industry of Metals Ores, Coal, Oil and Natural Gas – A Review. *Journal of Environmental Management*, 304: 114239. DOI: https://doi.org/10.1016/j.jenvman.2021.114239.

Kirsanov, A.K., Volkov, E.P., Kurchin, G.S., Shkaruba, N.A., Nafikov, R.Z., and Teshaev, U.R. (2022). The Central Asian States' Role in the World Mining Industry. *Journal of Degraded and Mining Lands Management*, 9(3): 3431-3443. DOI: https://doi.org/10.15243/jdmlm.2022.093.3431.

Klymenko, V. (2024). Public administration of environmental safety in Ukraine and EU countries. *Law. Human. Environment*, 15(4): 9-30. DOI: https://doi.org/10.31548/law/4.2024.09.

Kukhar, V.V., and Vasylevskyi, O.V. (2014). Experimental research of distribution of strains and stresses in work-piece at different modes of stretch-forging with rotation in combined dies. Metallurgical and Mining Industry, 6(3): 71-78.

Kuybida, V.V., Nekrasova, O.D., Kutsokon, Yu.K., Lopatynska, V.V., and Truskavetska, I.Ya. (2019). Summer fish kills in the Kaniv Reservoir. Hydrobiological Journal, 55(1): 103-106. DOI: https://doi.org/10.1615/HydrobJ.v55.i1.110.

Lumbroso, D., McElroy, C., Goff, C., Collell, M.R., Petkovsek, G., and Wetton, M. (2019). The Potential to Reduce the Risks Posed by Tailings Damsusing Satellite-Based Information. *International Journal of Disaster Risk Reduction*, 38: 101209. DOI: https://doi.org/10.1016/j.ijdrr.2019.101209.

Lyubchyk, A., Lygina, O., Lyubchyk, S., Fonseca, I., Tulepov, M., Mansurov, Z., and Lyubchik, S. (2015). Activated carbons from co-mingled liquid and solid organic wastes. Eurasian Chemico-Technological Journal, 17: 47-65. DOI: https://doi.org/10.18321/ectj339.

Magyar, D., Tischner, Z., Szabó, B., Freiler-Nagy, Á., Papp, T., Allaga, H., and Kredics, L. (2023). Characterization of Indoor Molds after Ajka Red Mud Spill, Hungary. *Pathogens*, 13(1): 22. DOI: https://doi.org/10.3390/pathogens13010022.

Nagy, G., Vida, G., Boros, L., and Ćirić, D. (2019). Decision Trees in Environmental Justice Research – a Case Study on the Floods of 2001 and 2010 in Hungary. *Open Geosciences*, 11(1): 1025-1034. DOI: https://doi.org/10.1515/geo-2019-0079.

Nunn, N. (2022). *The 2014 Mount Polley Mine Disaster: Environmental Injustice, Antirelationality, and Dreams of Unconstrained Futures*. Toronto: University of Toronto.

Pawul, M., Kępys, W., and Śliwka, M. (2022). The Role of Natural Succession in the Reclamation of Mining Waste Disposal Facilities. *Inżynieria Mineralna*, 1(2): 159-165. DOI: http://doi.org/10.29227/IM-2022-02-21.

Ramón, F., and Lull, C. (2019). Legal Measures to Prevent and Manage Soil Contamination and to Increase Food Safety for Consumer Health: The Case of

Spain. *Environmental Pollution*, 250: 883-891. DOI: https://doi.org/10.1016/j.envpol.2019.04.074.

Rose, R.L., Mugi, S.R., and Saleh, J.H. (2023). Accident Investigation and Lessons Not Learned: AcciMap Analysis of Successive Tailings Dam Collapses in Brazil. *Reliability Engineering and System Safety*, 236: 109308. DOI: https://doi.org/10.1016/j.ress.2023.109308.

Shakenov, A., Abdiev, A., and Stolpovskikh, I. (2023). Energy Potential of Mining Transport at Mines of Kyrgyzstan Located at High Altitude. *IOP Conference Series: Earth and Environmental Science*, 1254(1): 012142. DOI: https://doi.org/10.1088/1755-1315/1254/1/012142.

Shevko, V., Aitkulov, D., and Badikova, A. (2022). Comprehensive Processing of Vanadium-Containing Black Shale Tailings. Periodica Polytechnica Chemical Engineering, 66(4): 617-628. DOI: https://doi.org/10.3311/PPch.20050.

Shevko, V.M., Aytkulov, D.K., Atamkulov, B.B., Izbaskhanov, K.S., and Naimanbaev, M.A. (2017). Complex electrothermic processing of the poor oxide ore of the Achisay deposit. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 4(424): 177-183.

Shevko, V.M., Zharmenov, A.A., Aitkulov, D.K., and Terlikbaeva, A.Z. (2021). Complex processing of oxidized copper and zinc oxide ores with simultaneous production of several products. Physicochemical Problems of Mineral Processing, 57(1), 226-249. DOI: https://doi.org/10.37190/ppmp/131091.

Shirin, L., Korovyaka, Y., and Tokar, L. (2011). Justification of design parameters of compact load-haul dumper to mine narrow vein heavy pitching deposits. Technical and Geoinformational Systems in Mining: School of Underground Mining 2011, 1: 85-92. DOI: https://doi.org/10.1201/b11586-16.

Shumka, S., Kalogianni, E., Šanda, R., Vukić, J., Shumka, L., and Zimmerman, B. (2020). Ecological particularities of the critically endangered killifish Valencia letourneuxi and its spring-fed habitats: A long-lost endemic species of south Albania. Knowledge and Management of Aquatic Ecosystems, 2020-January(421): 45. DOI: https://doi.org/10.1051/kmae/2020036.

Simagambetov, B., and Seitkozha, Y. (2024). The Impact of the Environmental Problem Son the Protest Movementin Contemporary Society (Kyrgyzstan's Case). In: N. Ketenci (Ed.), *Transition to the Circular Economy Model: The Case of Turkey* (pp. 133-144). Cham: Springer.

Skliar, V., Smoliar, N., Kozak, M., Liubynskyi, O., and Skliar, Y. (2024). Ecological and cenotic features of natural regeneration of forests in the Left-Bank Polissya of Ukraine. Ukrainian Journal of Forest and Wood Science, 15(2): 118-134. DOI: https://doi.org/10.31548/forest/2.2024.118.

Sternberg, T., Toktomushev, K., and Ichinkhorloo, B. (2021). *The Impact of Mining Life Cycles in Mongolia and Kyrgyzstan: Political, Social, Environmental and Cultural Contexts*. London: Routledge.

Sydorchuk, P., Khlyap, G., and Andrukhiv, A. (2001). Growth and some properties of heterostructures based on new narrow-gap semiconductor ZnCdHgTe. Crystal Research and Technology, 36(4-5): 361-369. DOI: https://doi.org/10.1002/1521-4079(200106)36:4/5<361::AID-CRAT361>3.0.CO;2-5.

Talukder, P., Ray, R., Sarkar, M., Das, A., and Chakraborty, S. (2024). Adverse Effects of Mining Pollutant on Terrestrial and Aquaticenvironment an Ditsremediation.

Environmental Quality Management, 33(4): 595-610. DOI: https://doi.org/10.1002/tqem.22121.

Wolkersdorfer, C., and Mugova, E. (2022). Effects of Mining on Surface Water. In: K. Irvine, D. Chapman, S. Warner (Eds.), *Encyclopedia of Inland Waters* (pp. 170-188). Amsterdam, Oxford, Cambridge: Elsevier.

Yarin, A., Prado, J., Pozo, A., Carpiol, F.D., Patricio, S., and Surichaqui, B. (2023). Quality Management and Customer Satisfaction in SMEs in the Textile Industry. Journal of Textile and Apparel, Technology and Management, 12(4): 1-9. DOI: https://jtatm.textiles.ncsu.edu/index.php/JTATM/article/view/20052.

Yaroshenko, N., Skliar, V., and Rosenthal, G. (2023). Evaluation of ontogenetic and vital structures of stelliaria holostea l. in beech forests in the South of Low Saxony, Germany. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 23(3.2): 325-332. DOI: https://doi.org/10.5593/sgem2023V/3.2/s14.40.

You, G., and Wijesinghe, D.R. (2016). Mining and the Environment. In: S. Devasahayam, K. Dowling, M.K. Mahapatra (Eds.), *Sustainability in the Mineral and Energy Sectors* (pp. 245-260). Boca Raton: Taylor & Francis Group.

Zakeri, B., Hunt, J. D., Laldjebaev, M., Krey, V., Vinca, A., Parkinson, S., and Riahi, K. (2022). Role of Energy Storage in Energy and Water Security in Central Asia. *Journal of Energy Storage*, 5: 104587. DOI: https://doi.org/10.1016/j.est.2022.104587.

Zhusupov, B., Mirzaeva, A., and Orozbaeva, A. (2024). Legal Security of Tailings in Kyrgyzstan. *BIO Web of Conferences*, 116: 07019. DOI: https://doi.org/10.1051/bioconf/202411607019.

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Authors' Declarations and Essential Ethical Compliances

Author's Contributions (in accordance with ICMJE criteria for authorship)

This article is 100% contributed by the sole author. She conceived and designed the research or analysis, collected the data, contributed to data analysis & interpretation, wrote the article, performed critical revision of the article/paper, edited the article, and supervised and administered the field work.

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